SCENE Run Report

Hugh Lippincott

All Experimenter's Meeting

Nov. 25, 2013

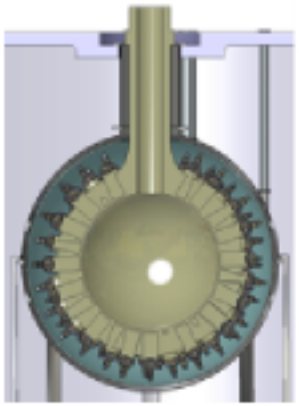
On Behalf of SCENE Collaboration: Scintillation and Ionization Efficiency of Noble Elements

Member Institutions:

Liquid Argon (LAr) as WIMP Target

Scintillation / S1: Excellent pulse shape discrimination (PSD) of nuclear (NR) versus electron recoils (ER)

Single-phase
S1 only

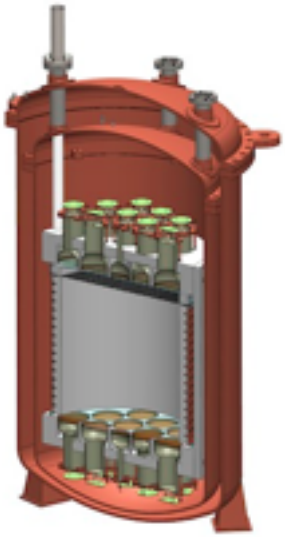


DEAP

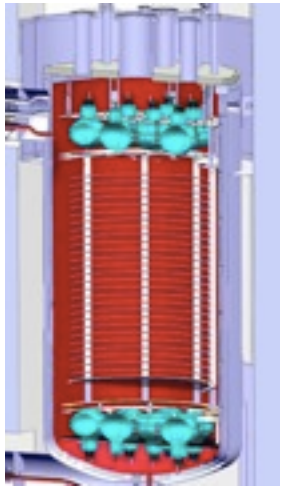
CLEAN

Ionization / S2: enables position reconstruction and additional ER discrimination

Dual-phase
S1+S2



DarkSide



ArDM

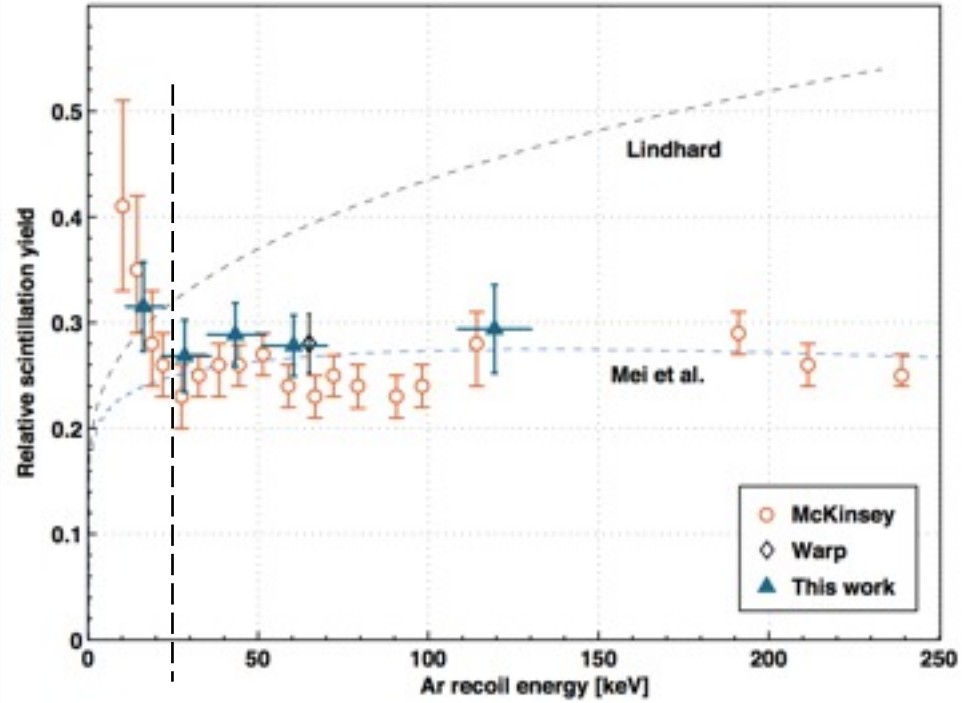
Scintillation and Ionization Yield for Nuclear Recoils

- Knowledge of those quantities is required to convert a NR signal to the deposited energy
- They decide the energy threshold of LAr detectors and inferred WIMP mass

Scintillation:
Yield for low energy (<25 keV_r) NR has not been precisely determined in the literature (the famous L_eff parameter)

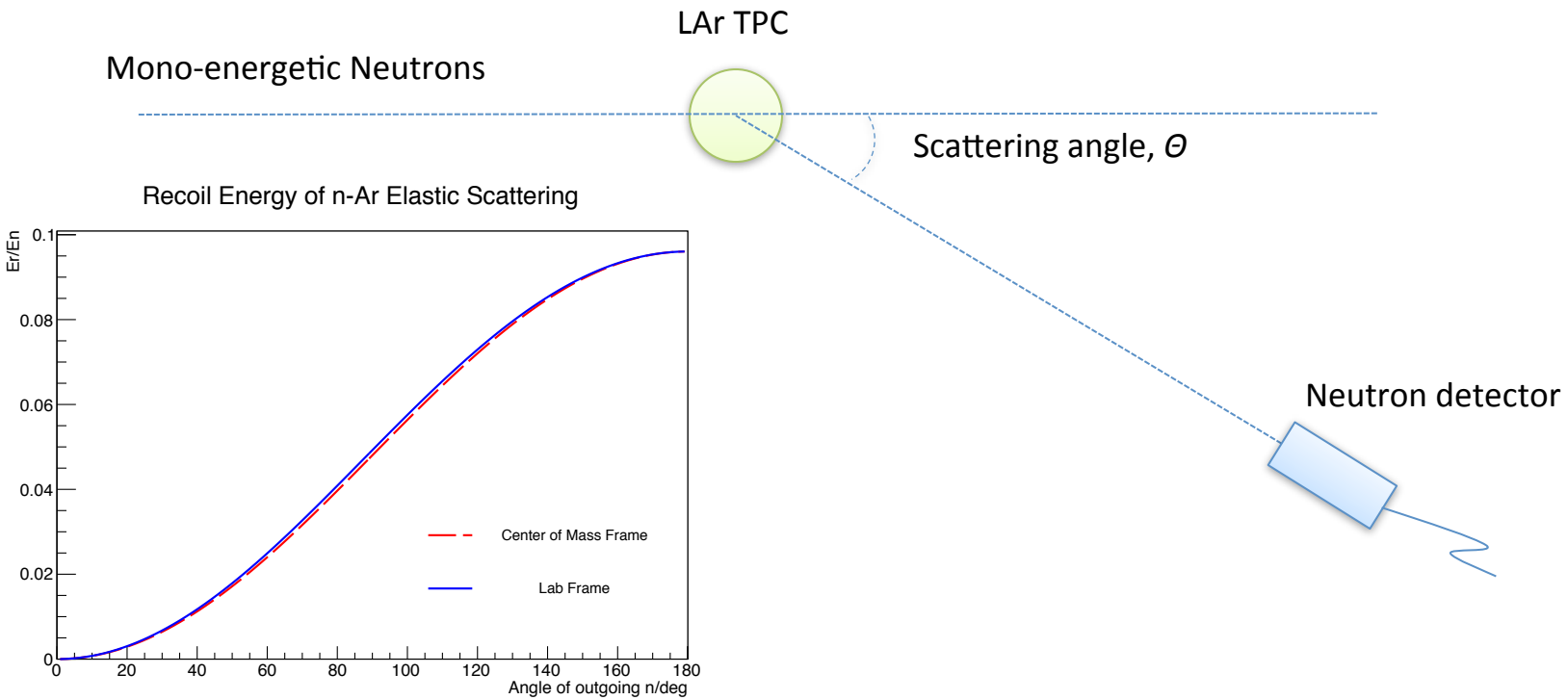
Effects of applied electric field (both on PSD and quenching factor) need to be characterized for two-phase Ar time projection chamber (LAr-TPC)

Ionization:
No comprehensive measurement of the ionization yield has been published



C. Regenfus et. al., J. Phys.: Conf. Ser. 375 (2012) 012019

Experimental Scheme

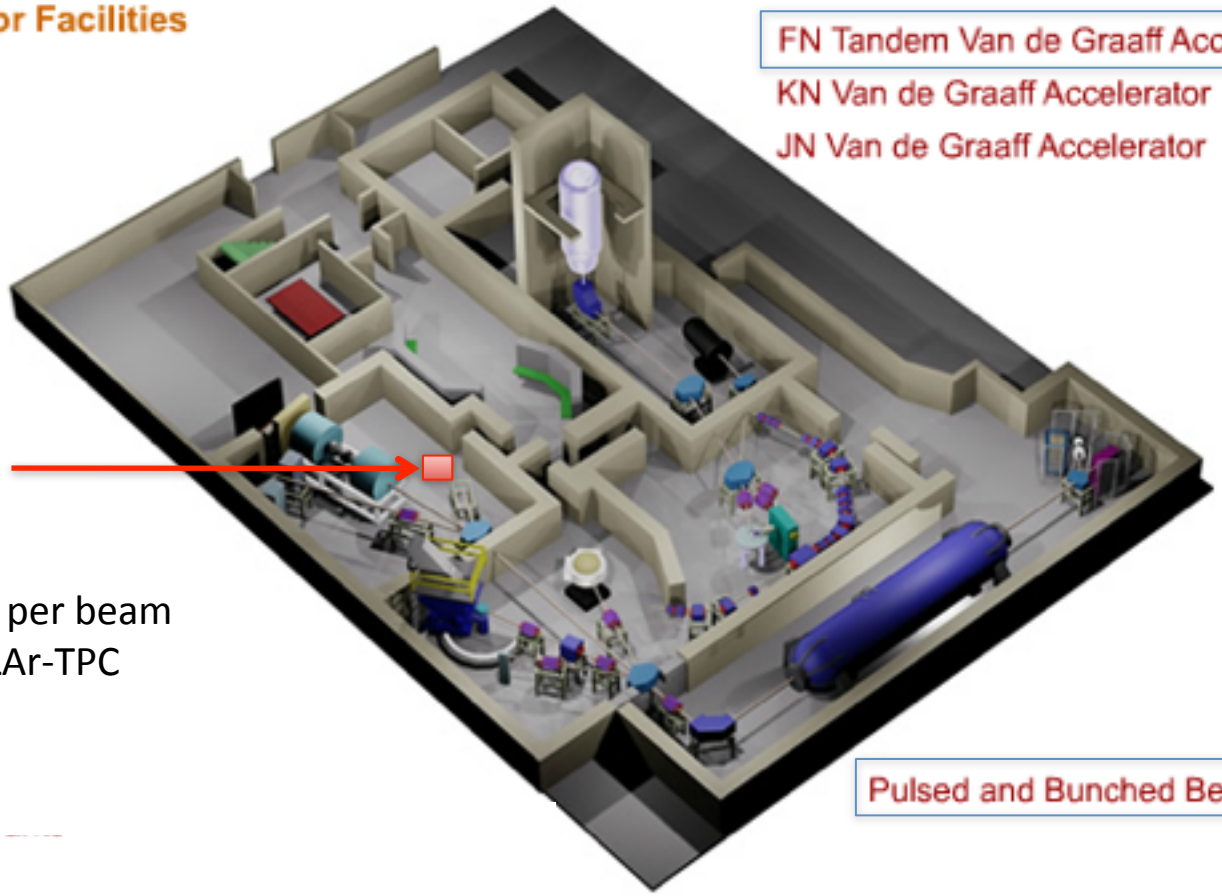


The Challenges

1. Compact LAr detector to minimize multiple scatterings

2. Unambiguously select NRs of a known energy

Proton Beam at University of Notre Dame



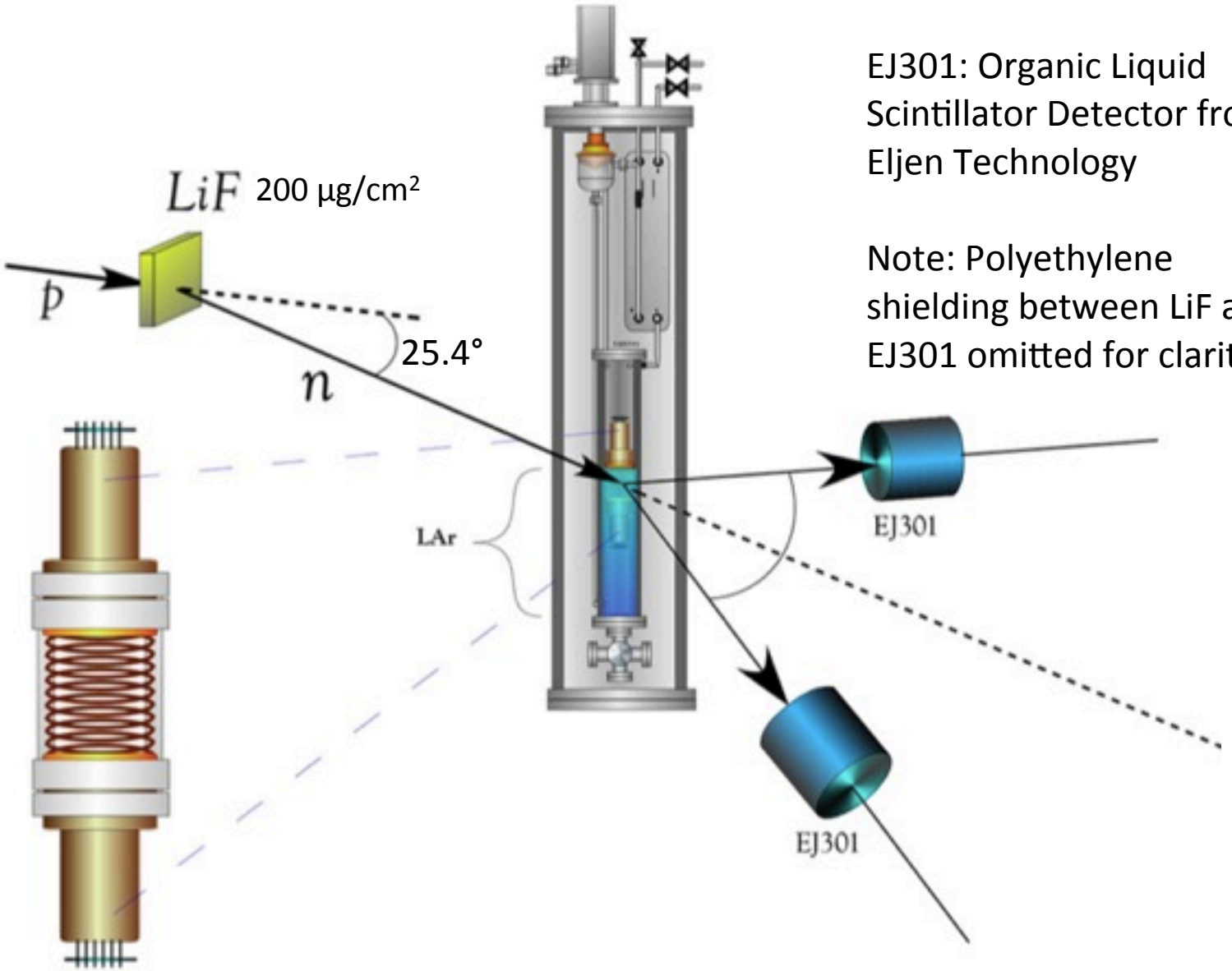
SCENE setup

~ 10^{-4} neutrons per beam pulse through LAr-TPC

- period = 101.5 ns or its multiples
  used 203 ns
- max current = 300 nA
  used ~50 nA

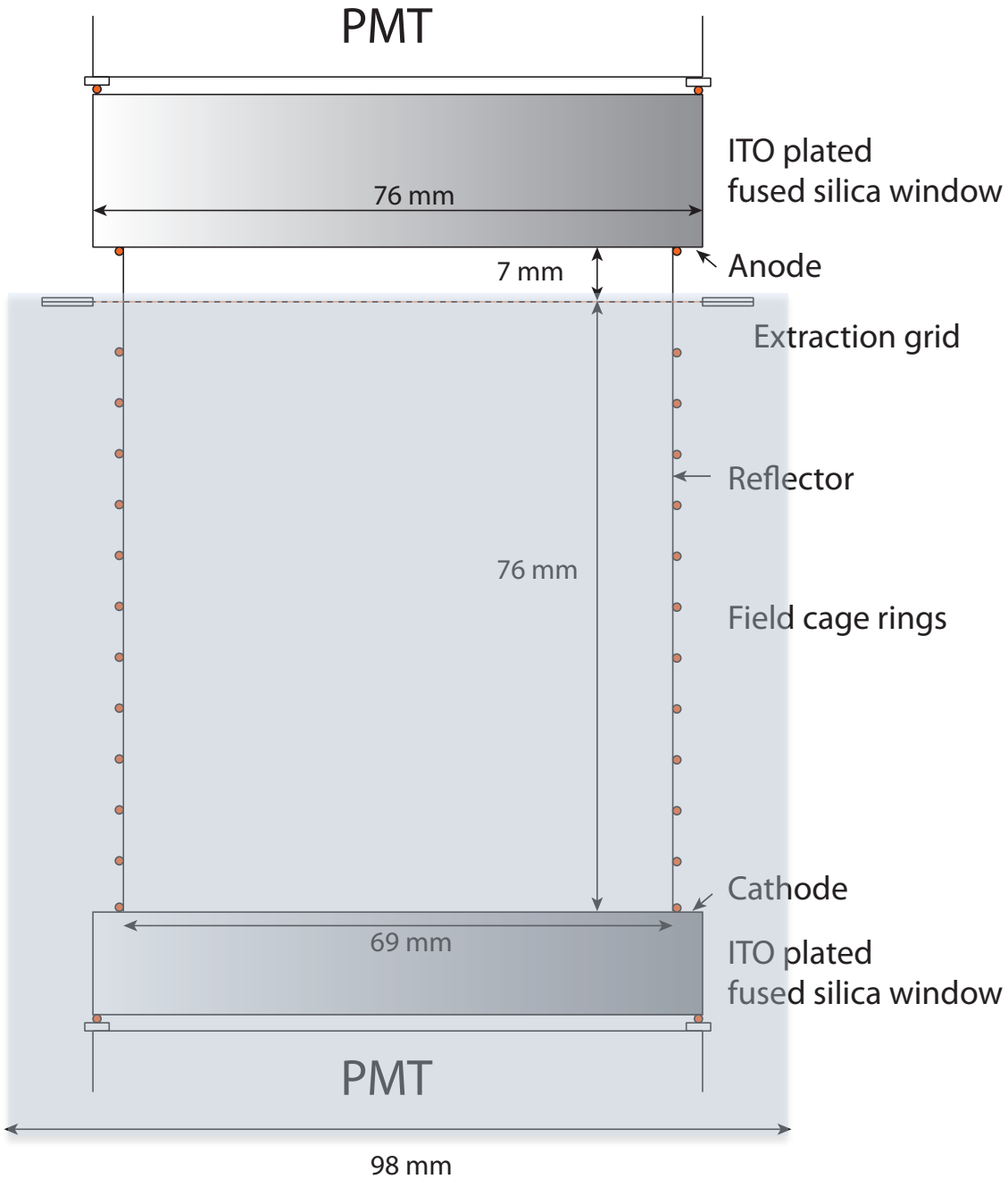
- beam angle spread at target < 0.006 deg
- ±1 keV mean uncertainty
- ±2 keV spread
- 10 MeV maximum

Experimental Layout



EJ301: Organic Liquid Scintillator Detector from Eljen Technology

Note: Polyethylene shielding between LiF and EJ301 omitted for clarity


PMT
ITO plated
fused silica window
76 mm
7 mm
Anode
Extraction grid
Reflector
76 mm
Field cage rings
Cathode
69 mm
ITO plated
fused silica window
PMT
98 mm

SCENE Schedule

May 20-27, 2013 - Scheduled beam run canceled after 1-2 days due to beam failure

June 17 - July 2, 2013 - Two week beam run dedicated to S1 light - Results in first physics publication, now accepted to PRD

PHYSICAL REVIEW D, VOLUME 00,

Observation of the dependence on drift field of scintillation from nuclear recoils in liquid argon

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We have exposed a dual-phase liquid argon time projection chamber (LAr-TPC) to a low energy pulsed narrow-band neutron beam, produced at the Notre Dame Institute for Structure and Nuclear Astrophysics, to study the scintillation light yield of recoiling nuclei. Liquid scintillation counters were arranged to detect and identify neutrons scattered in the LAr-TPC and to select the energy of the recoiling nuclei. We report the observation of a significant dependence (up to 32%) on the drift field of liquid argon scintillation from nuclear recoils of energies between 10.8 and 49.9 keV. The field dependence is stronger at lower energies. Since it is the first measurement of such an effect in liquid argon, this observation is important because, to date, estimates of the sensitivity of LAr-TPC dark matter searches are based on the assumption that the electric field has only a small effect on the light yield from nuclear recoils.

DOI: PACS numbers: 95.55.Vj, 29.40.Mc, 95.35.+d

Noble liquid time projection chambers (TPCs) are in widespread use to search for weakly interacting massive particle (WIMP) dark matter by detecting low energy nuclear recoils that would be produced by WIMP interactions [1–6]. A precise understanding of the scintillation light yield from nuclear recoils and its dependence on energy and drift field are key to the interpretation of results from present experiments and to estimates of the sensitivity of future detectors.

Measurements of the nuclear recoil light yield in liquid argon (LAr) have been performed in the absence of a drift field with monoenergetic neutrons and reported in [7,8]. For liquid xenon (LXe), several measurements have been performed with and without an applied electric field using both monoenergetic and broad spectrum neutron sources [9–21]. These measurements in LXe report that the applied electric field has a <10% effect on the nuclear recoil light yield that is independent of energy, although the strong dependence on the drift field of the scintillation yield, a dependence that increases with decreasing energy.

The experiment was performed at the University of Notre Dame Institute for Structure and Nuclear Astrophysics. Protons from the tandem accelerator [22] struck a 0.20-mg/cm^2-thick LiF target deposited on a 1-mm-thick aluminum backing, generating a neutron beam through the reaction ^{7}Li(p, n)^{7}Be. For this study, the proton beam energy was 2.376 or 2.930 MeV, depending on the desired nuclear recoil energy. The proton beam was bunched and chopped to provide 1-ns-wide pulses, separated by 101.5 ns, with an average of 6.3×10^4 protons per pulse. The accelerator pulse selector was set to allow one of every two proton bunches to strike the LiF target, giving one neutron beam pulse every 203.0 ns.

The design of the LAr-TPC closely follows that used in DarkSide-10 [5]. The active volume is contained within a 68.6 mm diameter, 76.2 mm tall, right circular polytetra-

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May 20-27, 2013 - Scheduled beam run canceled after 1-2 days due to beam failure

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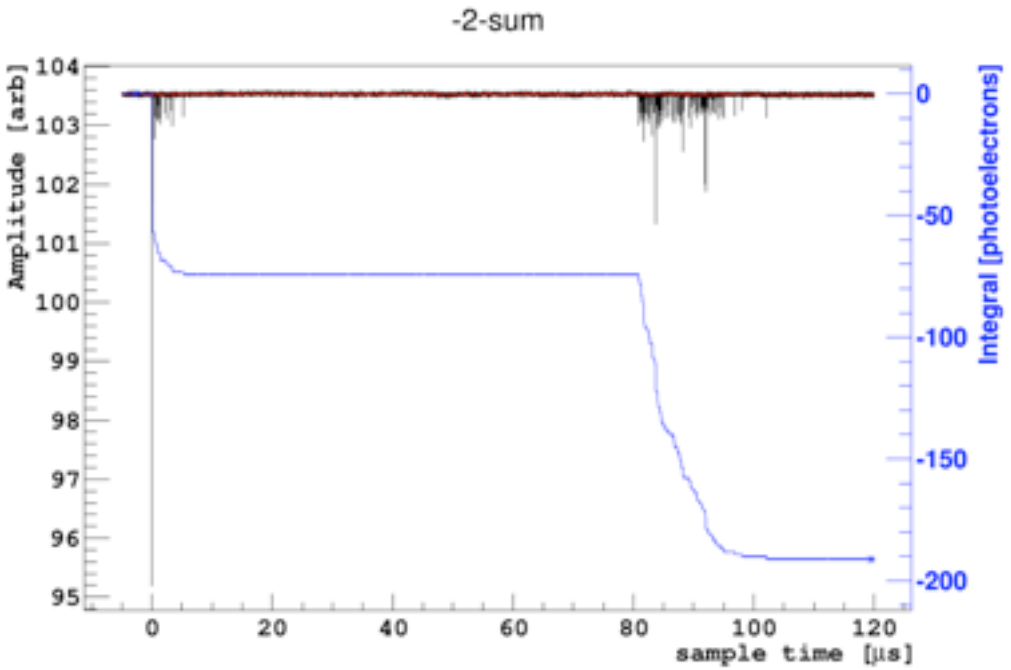
Oct. 21 - Nov. 4 - Two week beam run dedicated to S2 measurements



Run statistics

200 ug/cm^2 LiF target

TPC trigger rate (alone) between 1 kHz-4 kHz during run
-Important to keep overall rate down to protect the PMTs

Three proton energies
2.305, 2.921, 3.600 MeV

5 Nuclear recoil energies
7.5, 16.5, 26.1, 35.7, 57.6 keV

5 drift fields at each energy S2 runs
50, 100, 200, 300, 500 V/cm

~500 NR events per setting (per NR energy per drift field)

Run statistics

30-70 microsecond drift lifetime

-Slow degradation throughout the run, could be recovered by circulating through the purification loop for several hours

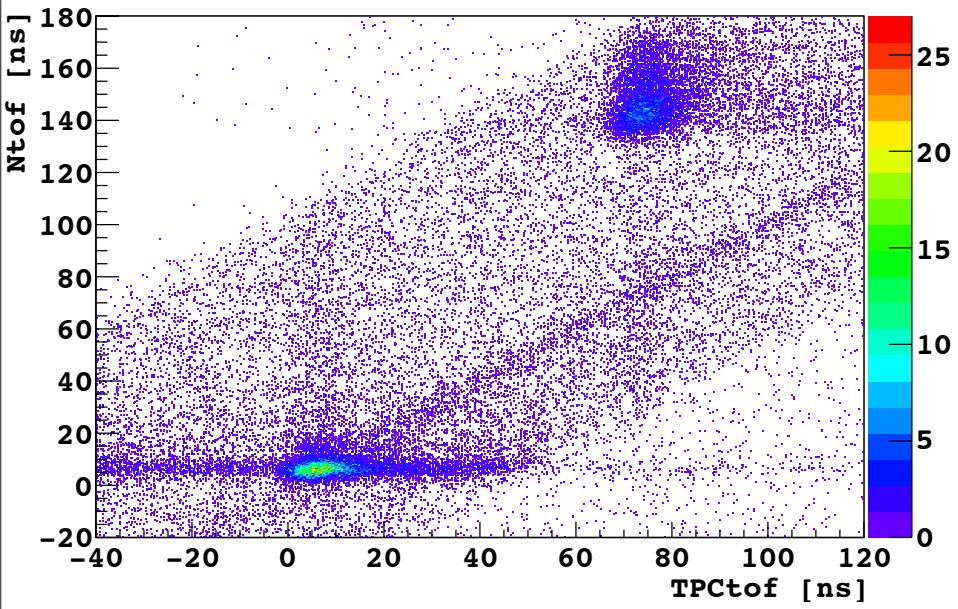
5-6 photoelectrons/keV light yield

-Top PMT single photoelectron and collection efficiency sagged with time

-Collection efficiency monitored continuously with external LED

- Light yield monitored via ^{83}Kr beta source (~40 keV, continuously injected into chamber)

Results (10.8 keV, E_{drift} = 1000 V/cm)

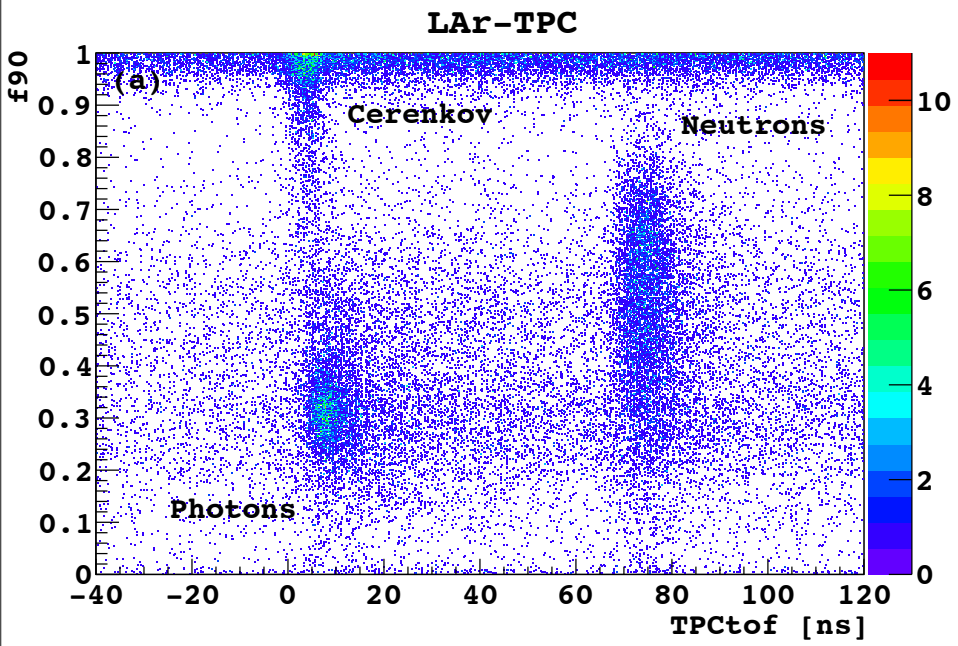


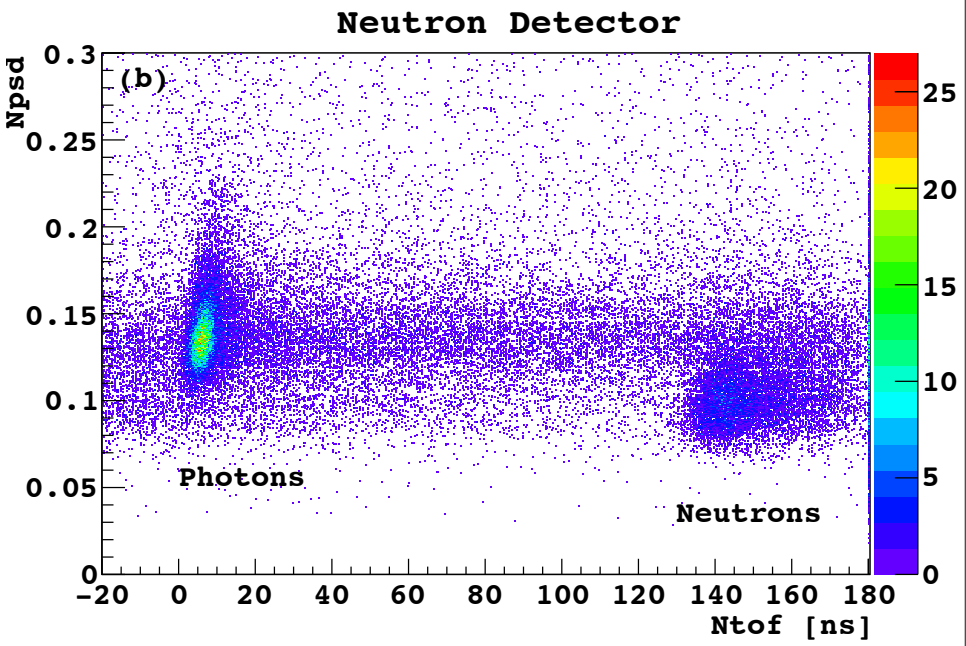
TPCtof: time difference between the proton-beam-on- target and the TPC signal

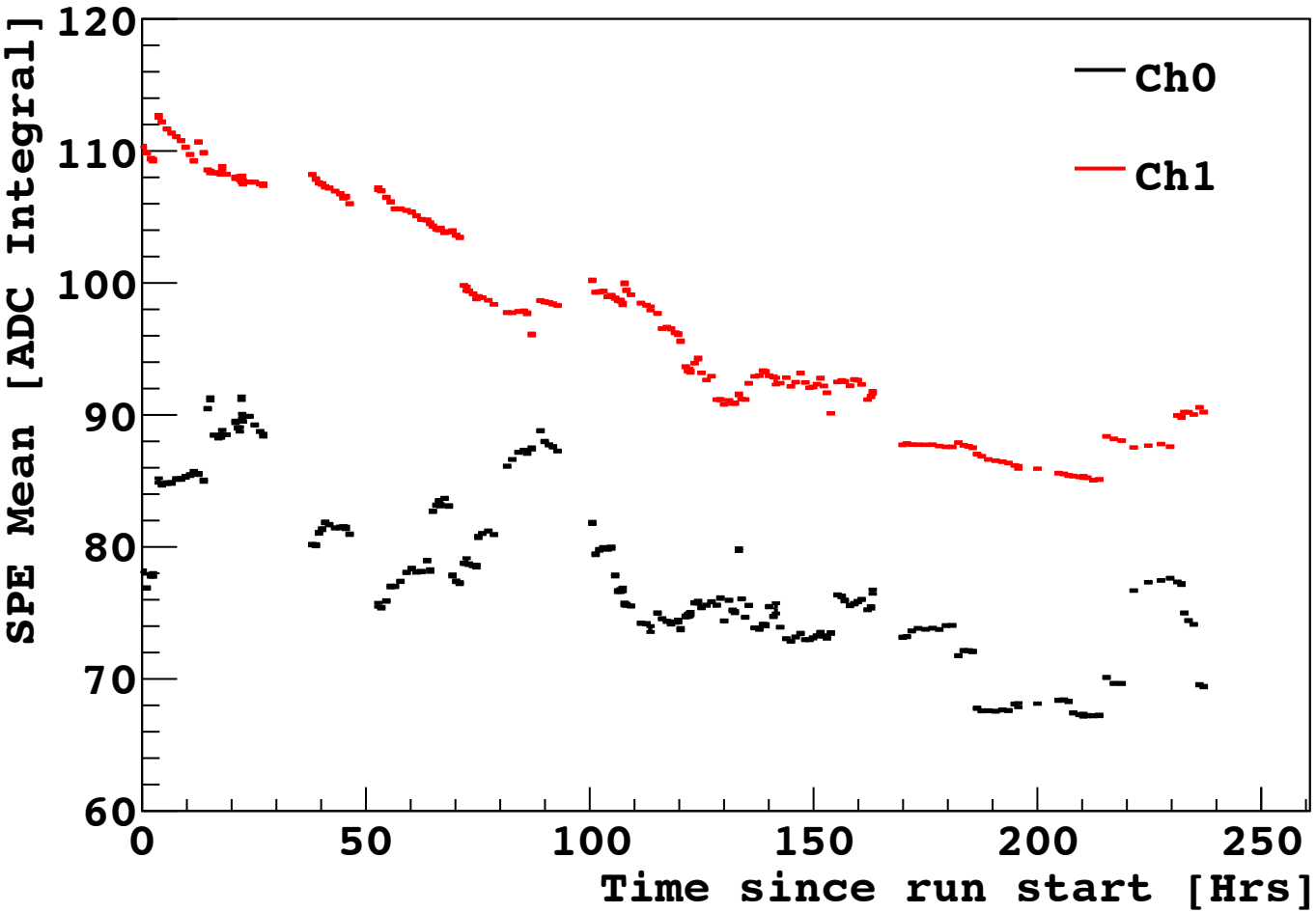
Ntof: time difference between the proton-beam-on-target and the neutron detector signal

F90: PSD parameter in LAr the fraction of light detected in the first 90 ns of an event

Npsd: peak over area in the neutron detector



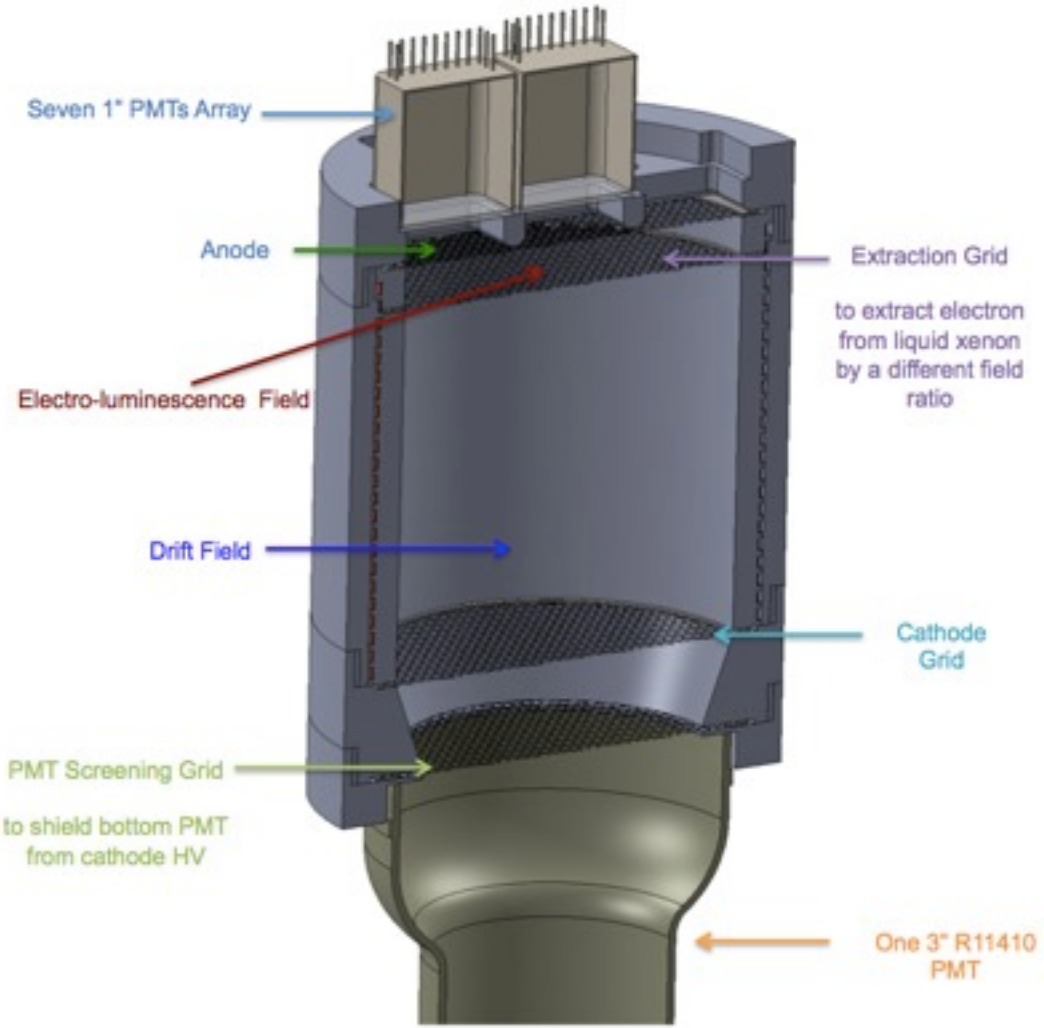



SPE Mean [ADC Integral]
120
110
100
90
80
70
60
0
50
100
150
200
250
Time since run start [Hrs]
Ch0
Ch1

Future Plans

- Finish analysis of both June and October data leading to a second paper on LAr ionization yield from nuclear recoils (including L_eff)

- Liquid Xe run in March with new TPC under construction at UCLA
  - Hugely relevant for low mass WIMP controversies, particularly in light of the LUX result



Y. Meng 2013, UCLA

Many thanks to:

Fermilab staff at PAB: *Bill Miner, Cary Kendziora, Ron Davis, Kelly Hardin

Notre Dame Institute for Structure and Nuclear Physics staff and students, especially those who took beam shifts during our run

Sidney Cahn and Kevin Charbonneau at Yale for help with the krypton source

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